Transition processes that end multi-year La Niña

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(Meehl et al., 2025: *npj Climate and Atmospheric Science,* https://doi.org/10.1038/s41612-025-01204-8.)

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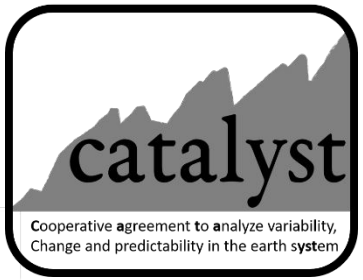


Smoke from the Australian bushfires in 2019-2020 has been shown to have contributed to the initiation of the "triple-dip" La Niña from 2020-2023. But what maintained the event and what processes ended it?

Perform two sets of initialized hindcasts with CESM2 and E3SM2

Both initialized in August 2019, and run initially for three years to July, 2022 (and later extended to March 2023);
Each has 30 ensemble members (results here shown for annual averages, August to July);
the models include an aerosol scheme whereby cloud condensation nuclei (CCN) and cloud albedo can be affected by smoke aerosols

--One set is run without Australian bushfire smoke emissions (standard "SMYLE", or "no-smoke" simulation with CESM2 and E3SM2);

--One set is run with the observed Australian bushfire smoke emissions from GFED ("smoke", otherwise the same as the standard SMYLE experiments with both models)

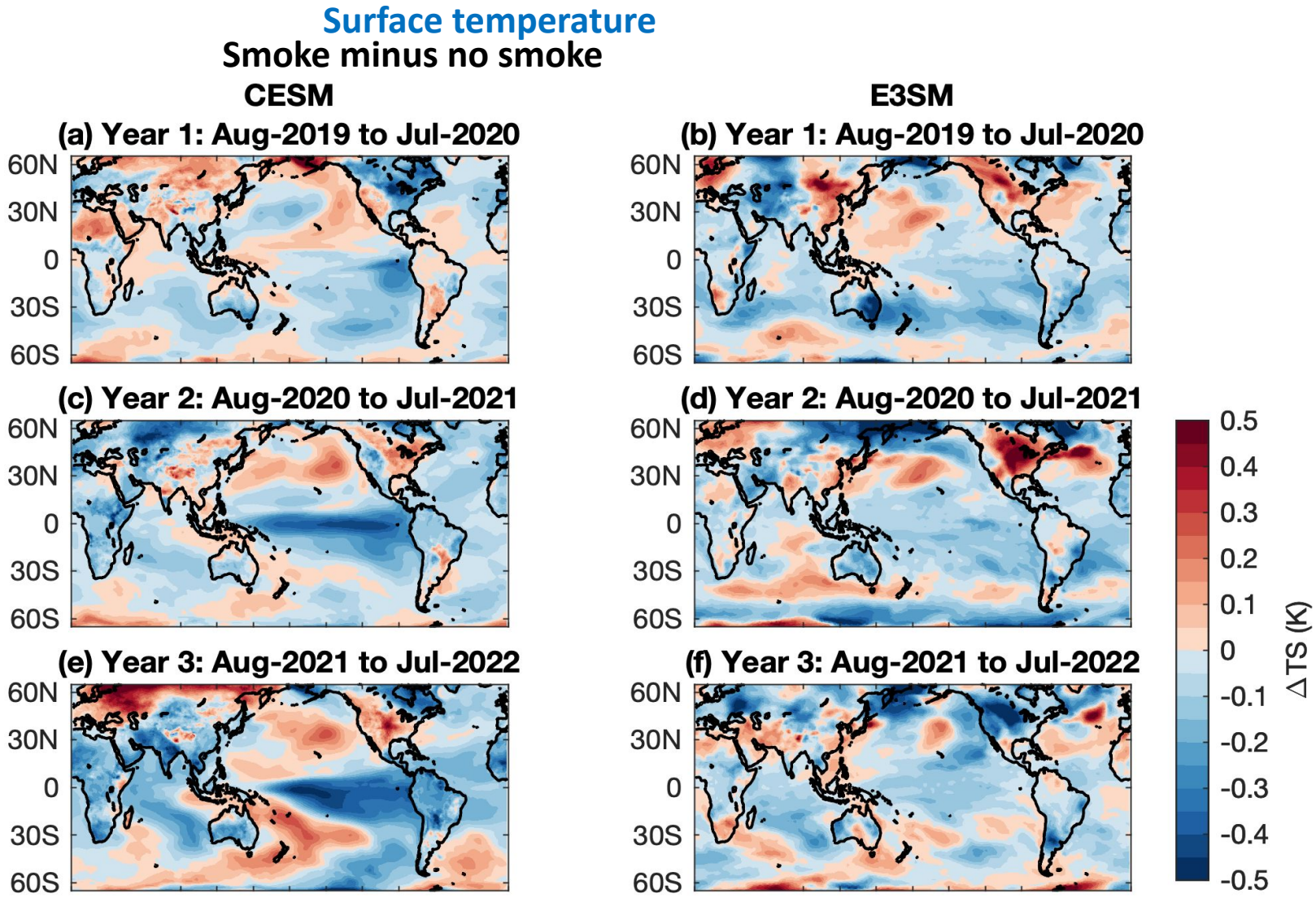
--Differences between these two initialized Earth system prediction experiments ("smoke minus no-smoke") show only the effects of the wildfire smoke

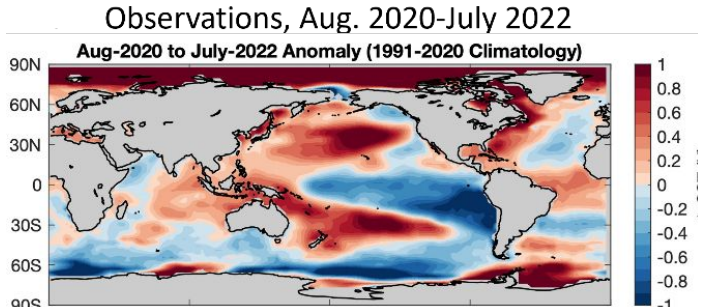
--By performing differences of parallel initialized experiments, model drift is identically removed

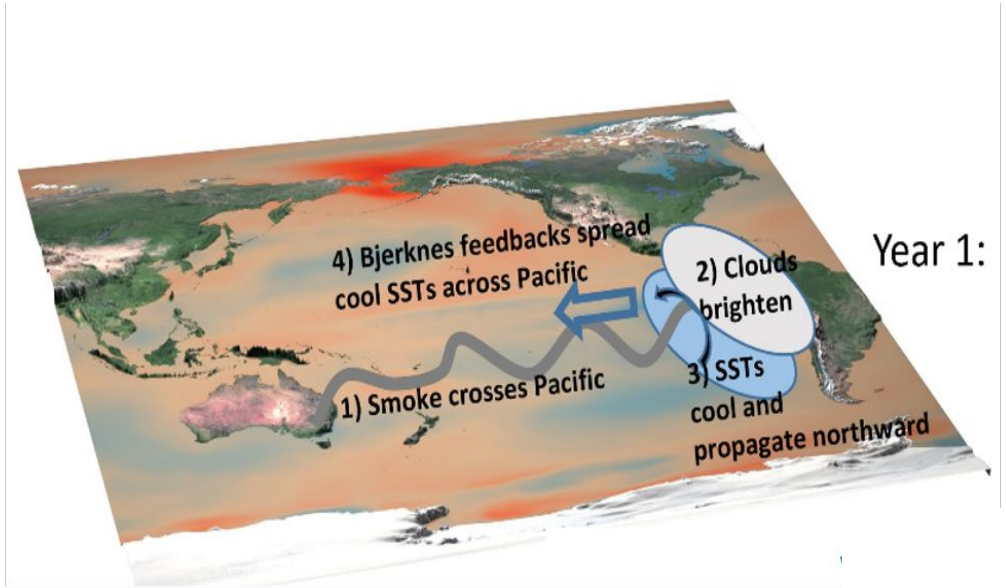
The La Niña-like SST anomalies persist for three years in the smoke minus no-smoke model differences

If the Australian wildfire smoke contributed to the initial La Niña-like response, and the smoke dissipated by March, 2020…

La Niña-like anomalies persist and grow into year 3 due to Bjerknes feedback

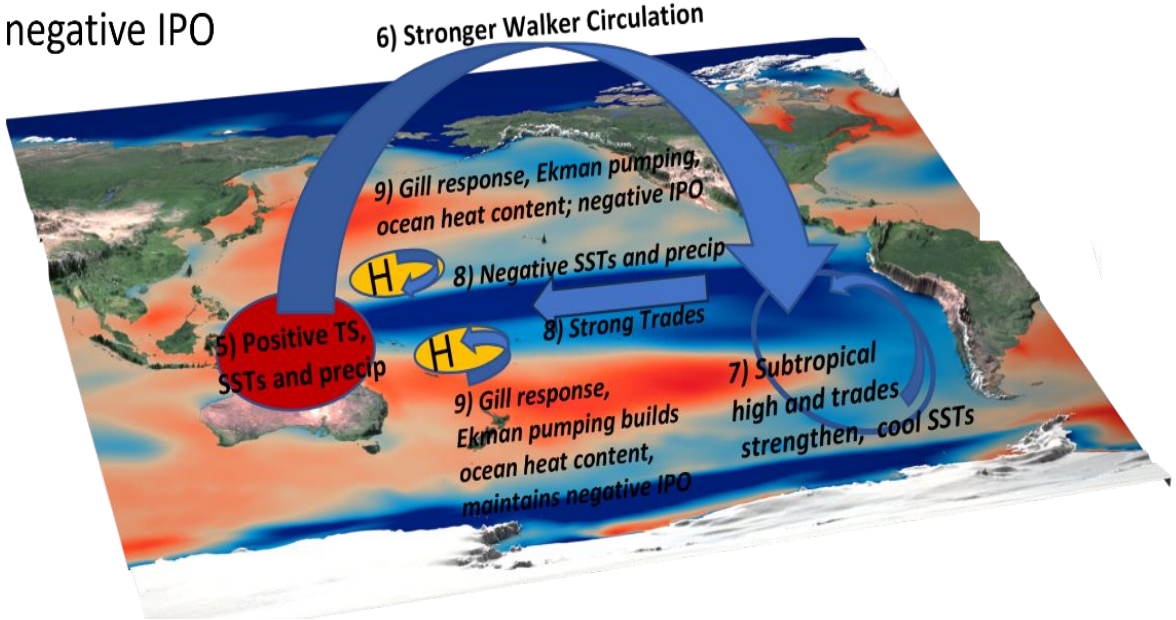






Year 1: Onset

Years 2 and 3: Sustained
3-year La Niña and
negative IPO



What are the processes that ended the multi-year La Niña?

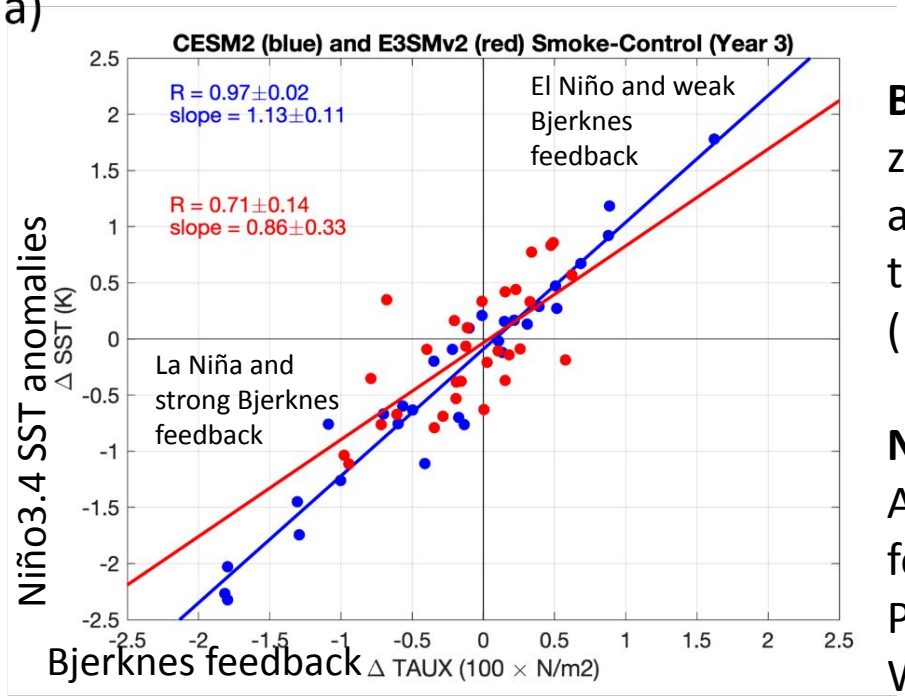
Bjerknes feedback plays a major role in sustaining the La Niña to 3 years in both models

In year 3, strongest Bjerknes feedback ensemble members produce strongest La Niña events (lower left quandrant of top panel), but some ensemble members with weaker Bjerknes feedback produce El Niño events in year 3 (upper right quadrant of top) as opposed to weaker La Niña events

This indicates that some ensemble members transition from La Niña to El Niño in year 3

But there is a preponderance of 3 year La Niña events in both E3SMv2 (red) and CESM2 (blue) (bottom)

a)



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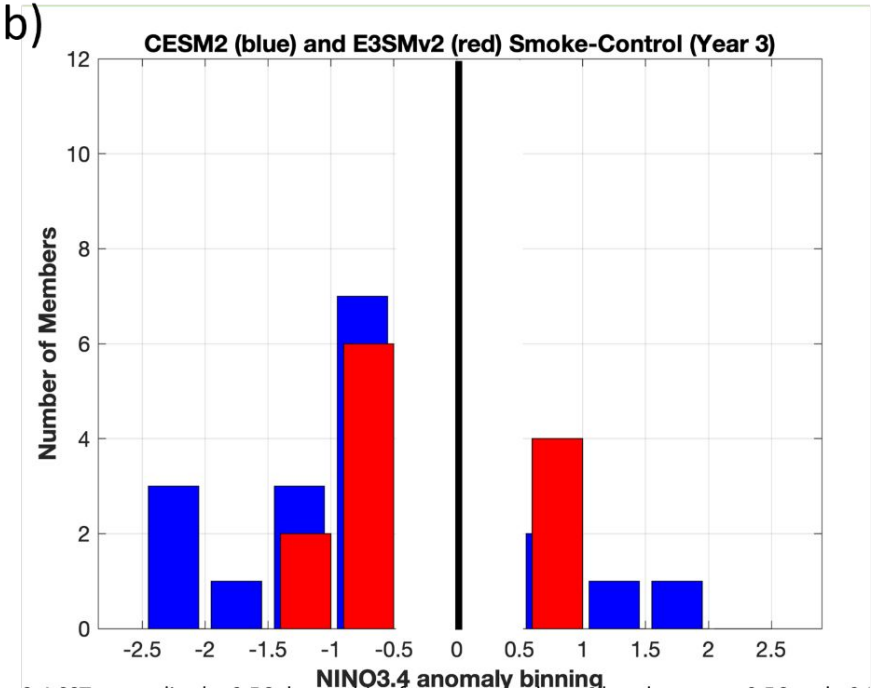


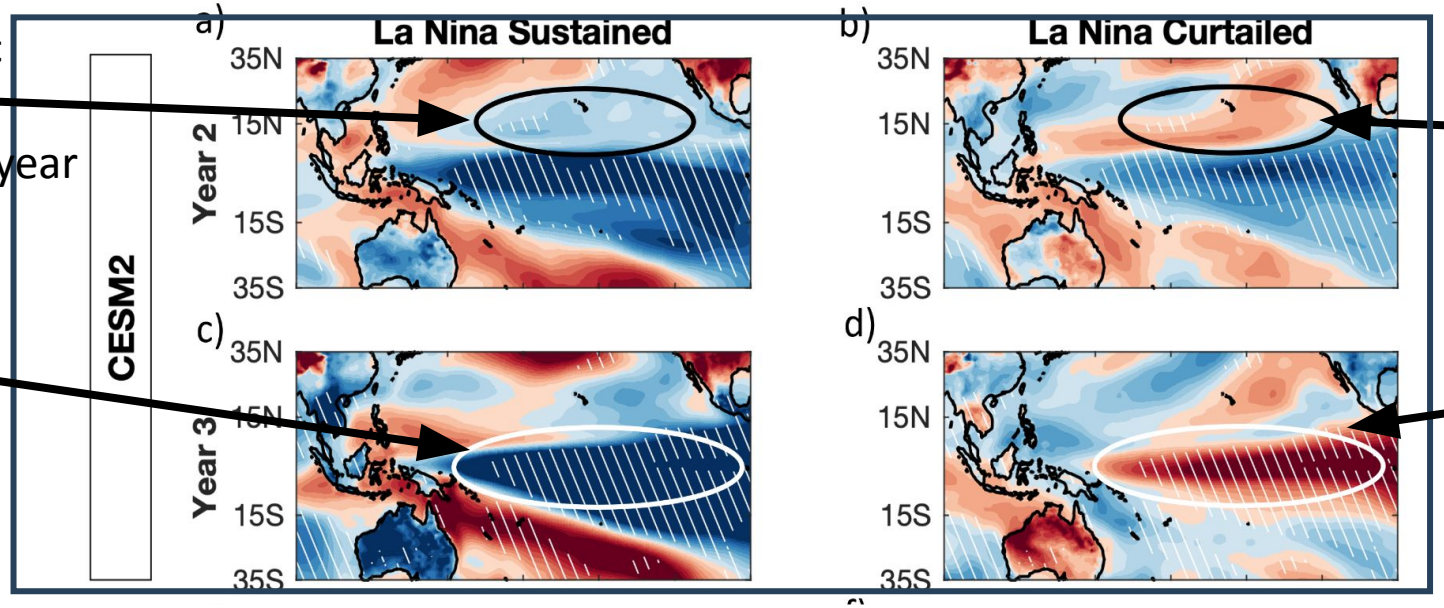
Bjerknes feedback index: zonal surface wind stress anomalies averaged across the equatorial Pacific basin (160°E–130°W; 5°S–5°N)

Niño3.4 SST anomalies: Area-averaged SST anomalies for the eastern equatorial Pacific region: 5°S–5°N, 170° W-120°W

Composite 5 strongest sustained La Niña events, and the 5 strongest curtailed events that transition to El Niño

Negative North Pacific Meridional Mode (NPMM) in sustained year 2

And sustains La Niña into year 3



Positive North Pacific Meridional Mode (NPMM) forms in curtailed year 2

And transitions to El Niño in year 3

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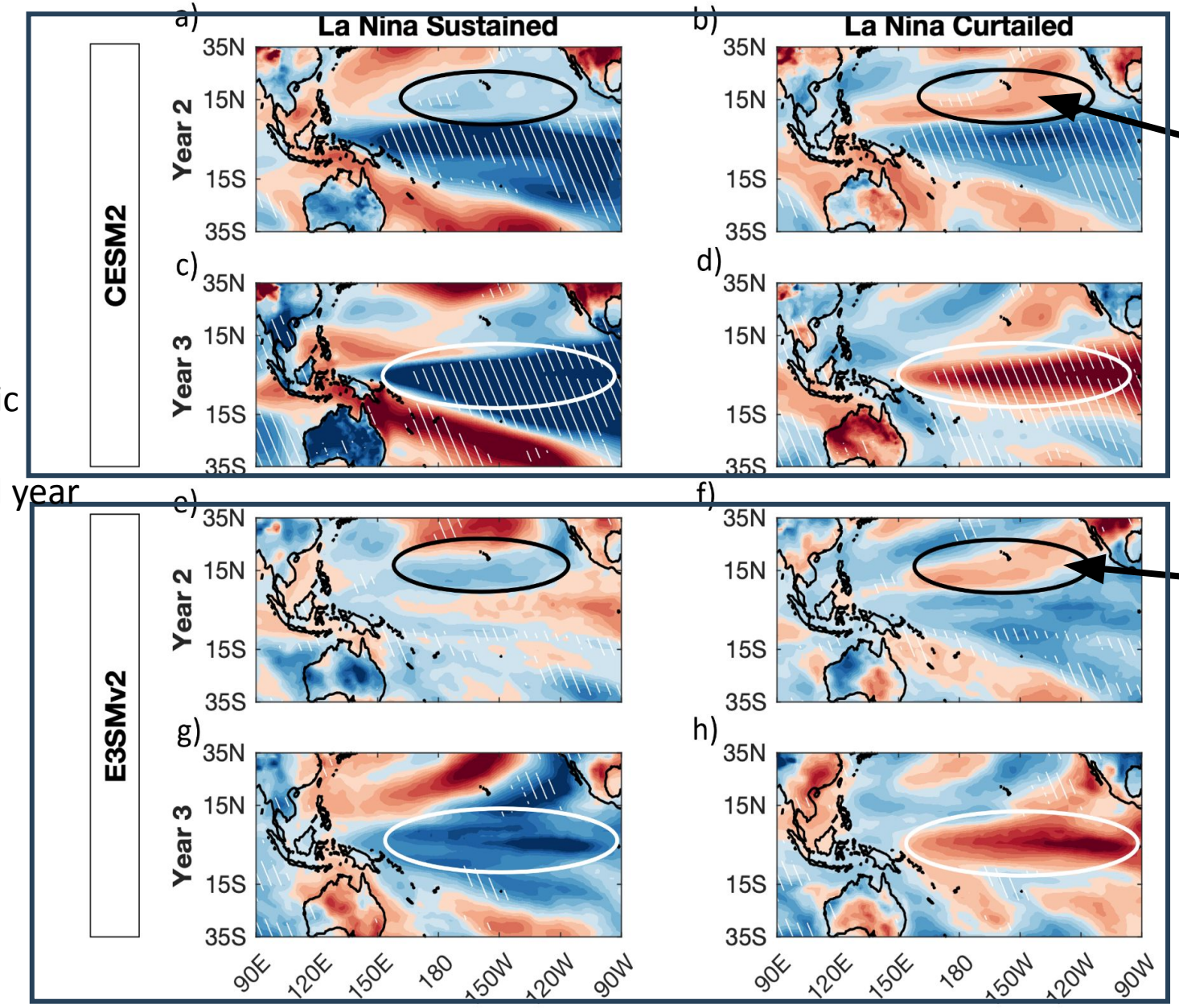

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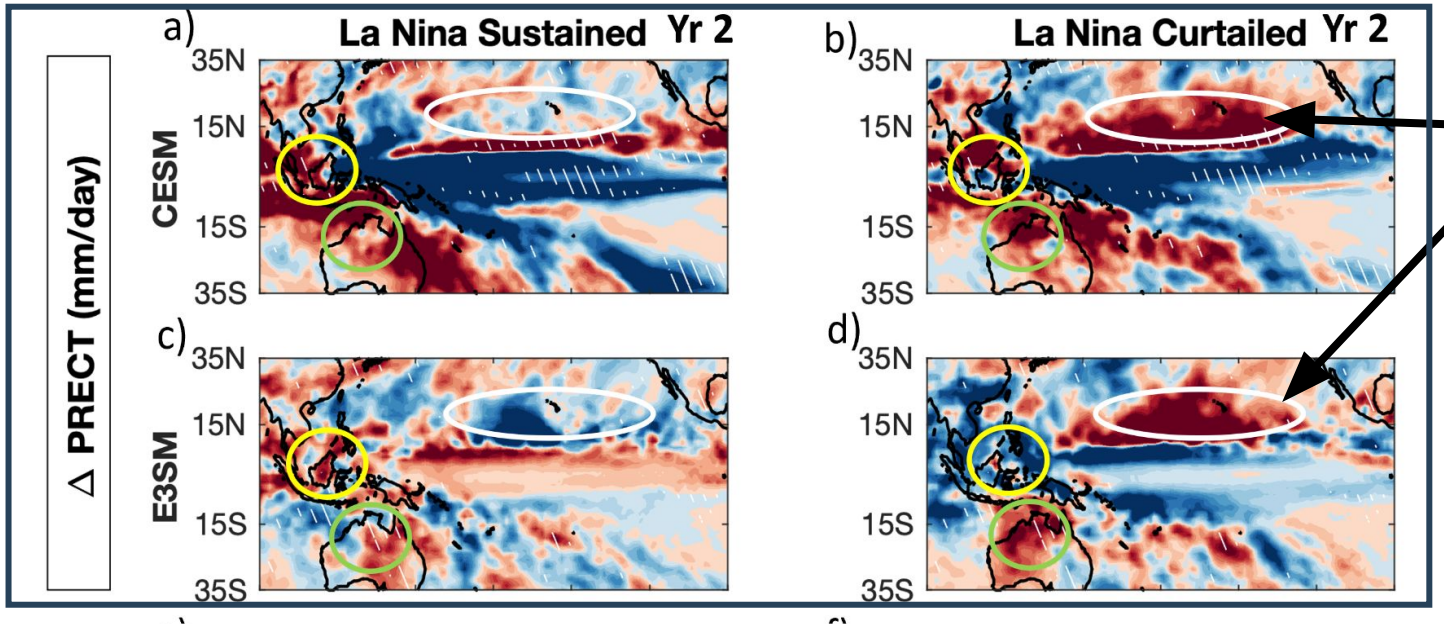
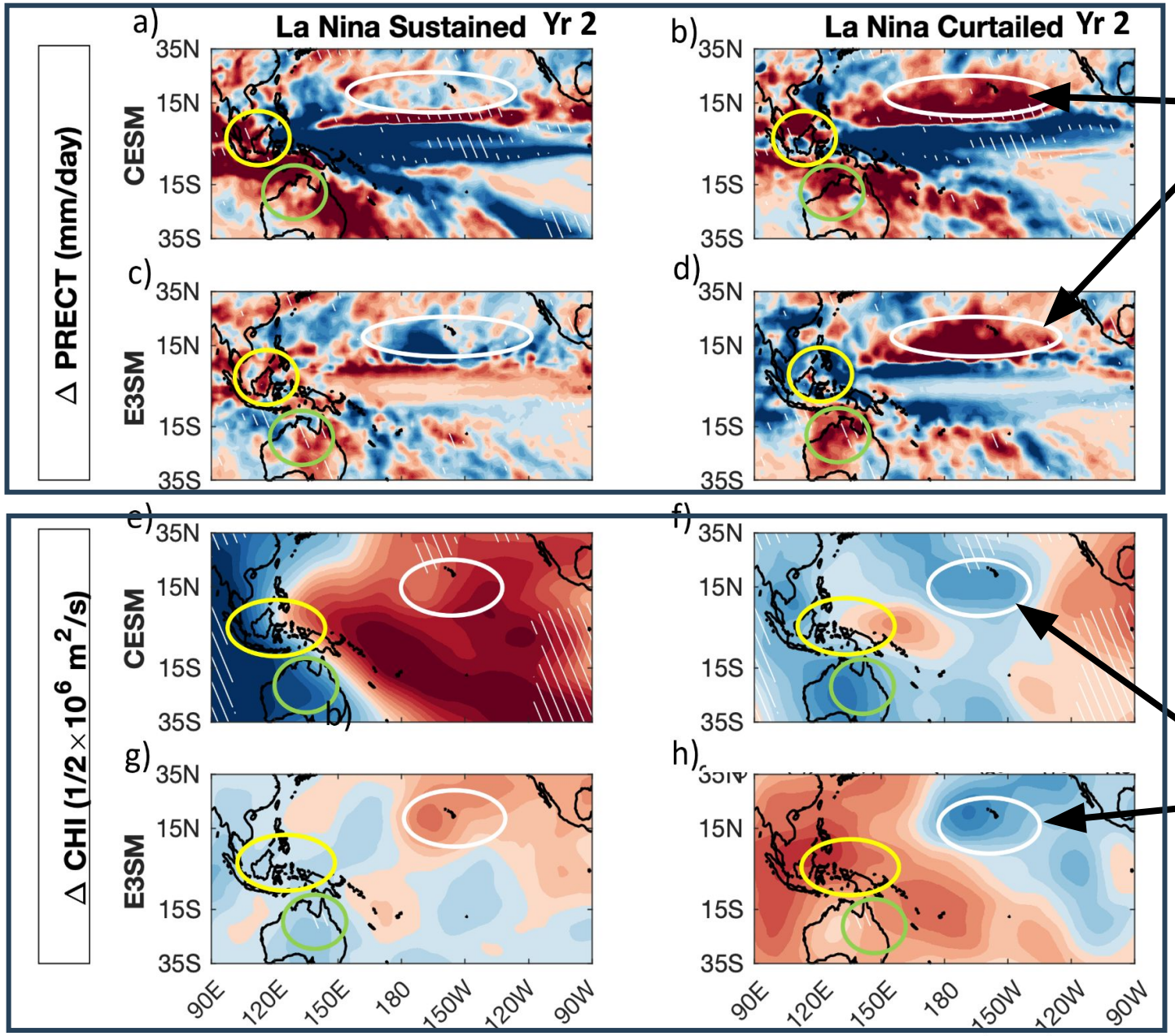


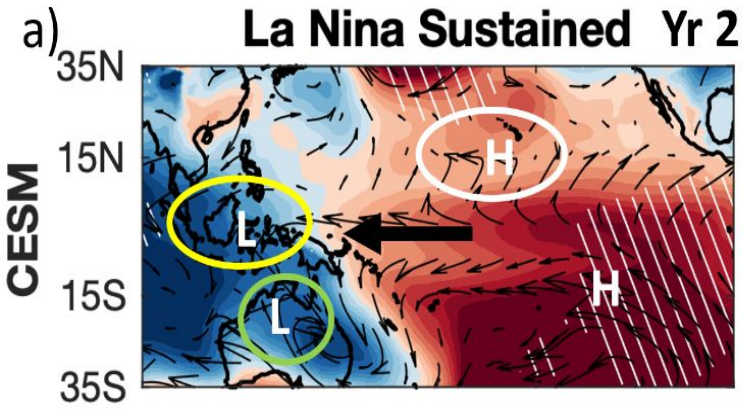
Positive precip anoms over positive NPMM SST anoms in curtailed year 2 in both models



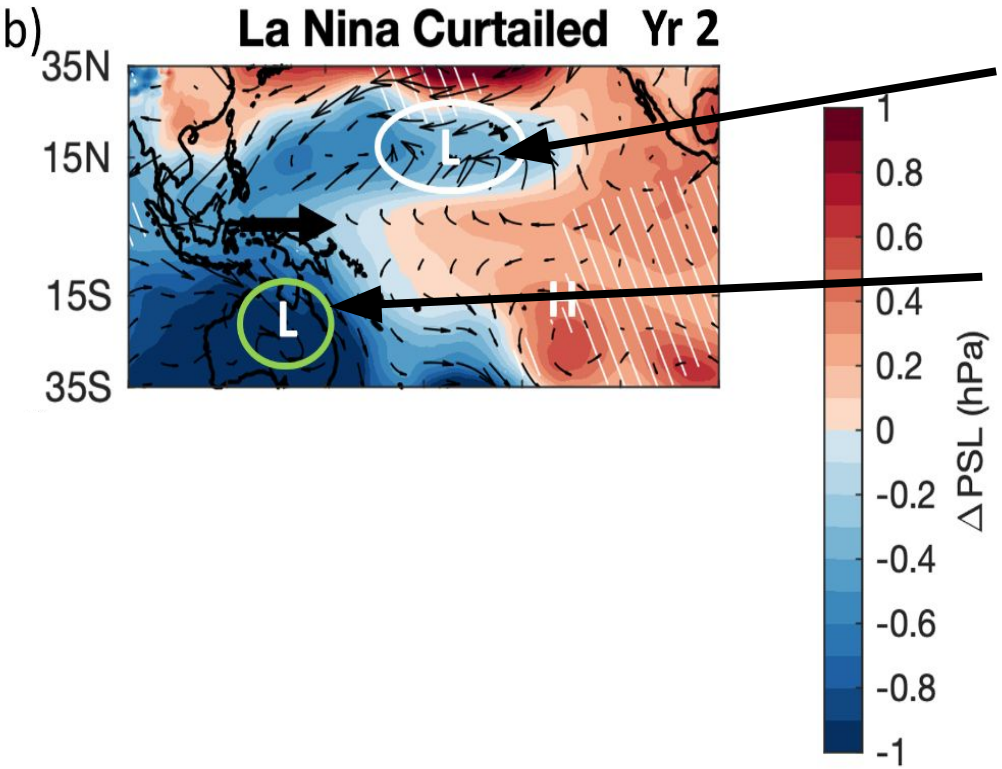
Positive precip anoms over positive NPMM SST anoms in curtailed year 2 in both models

Anomalous upper level outflow over positive precip anoms in curtailed year 2 produces negative 200 hPa Chi, and upper level convergence to west

Sea level pressure and surface wind vectors



Strong zonal SLP gradient maintains strong Trades and **continued La Niña**



Negative SLP anoms with positive precip anoms contribute to weakened Trades in Eq. Pac

Relatively stronger low pressure over northern Australia contributes to meridional SLP gradient, westerly surface wind anomalies in Eq. W. Pac., downwelling ocean Kelvin waves, deepened thermocline in E. Eq. Pac. and **transition to El Niño**

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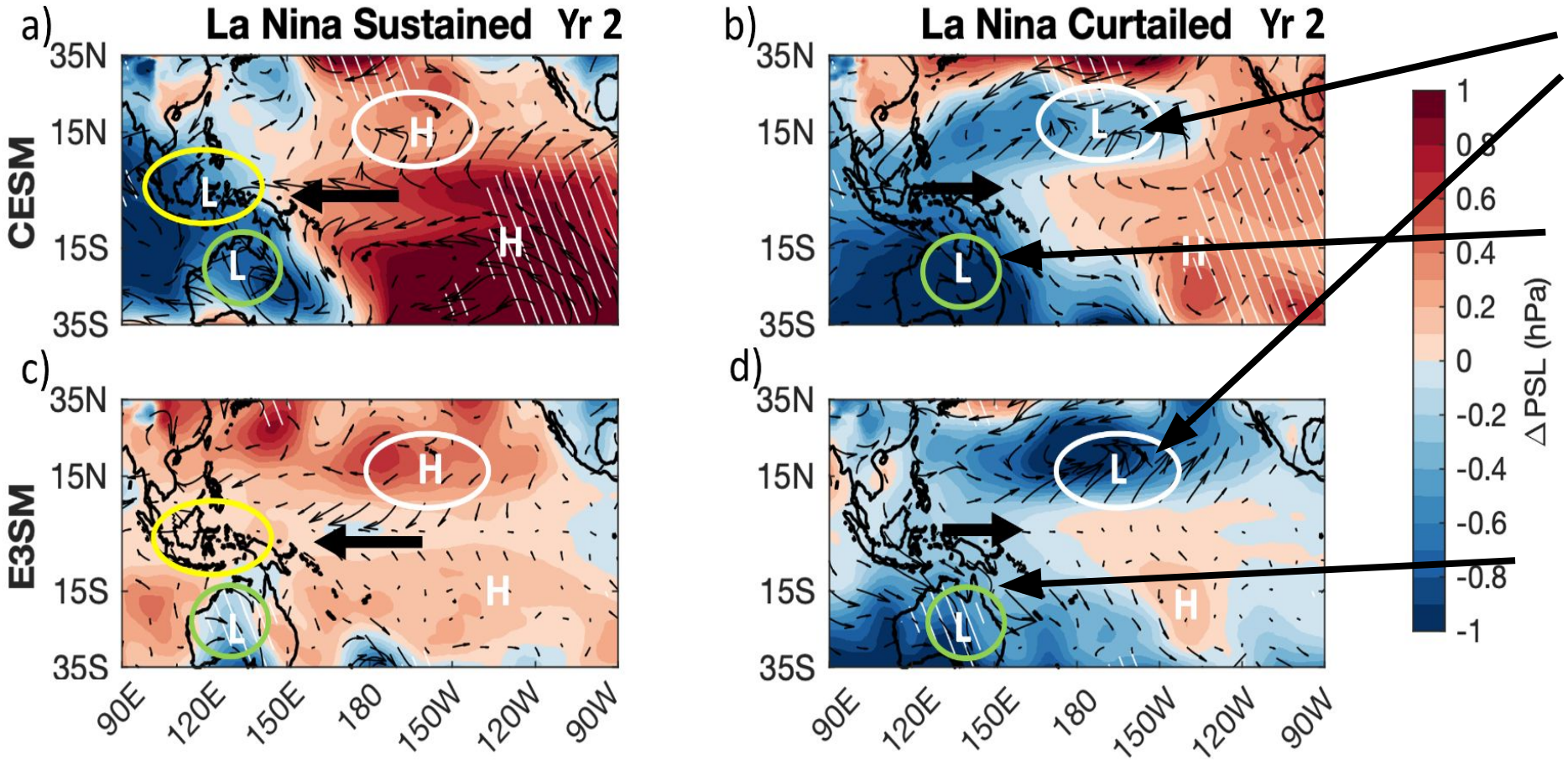

Strong anomalous high in region of negative NPMM maintains strong Trades and **continued La Niña**

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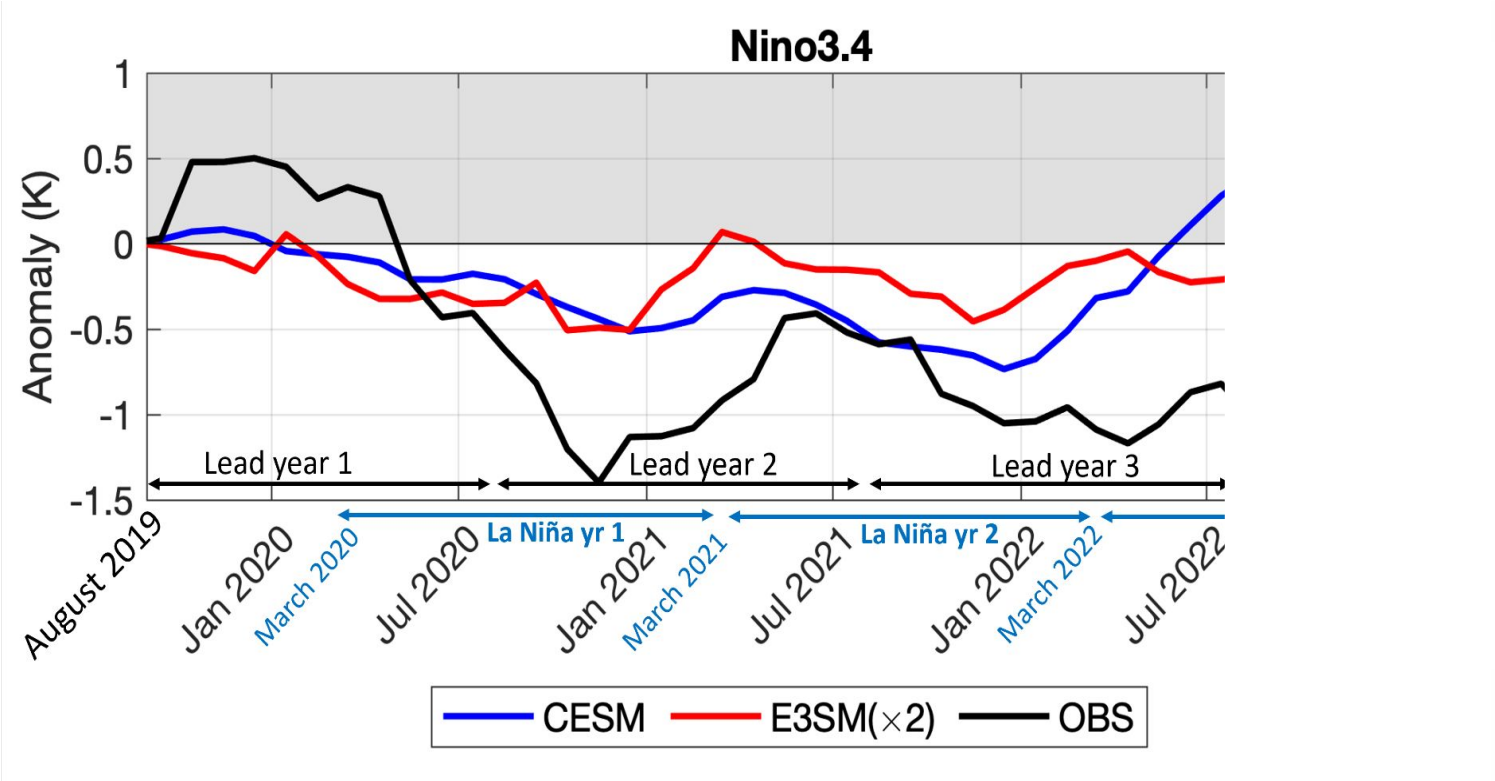
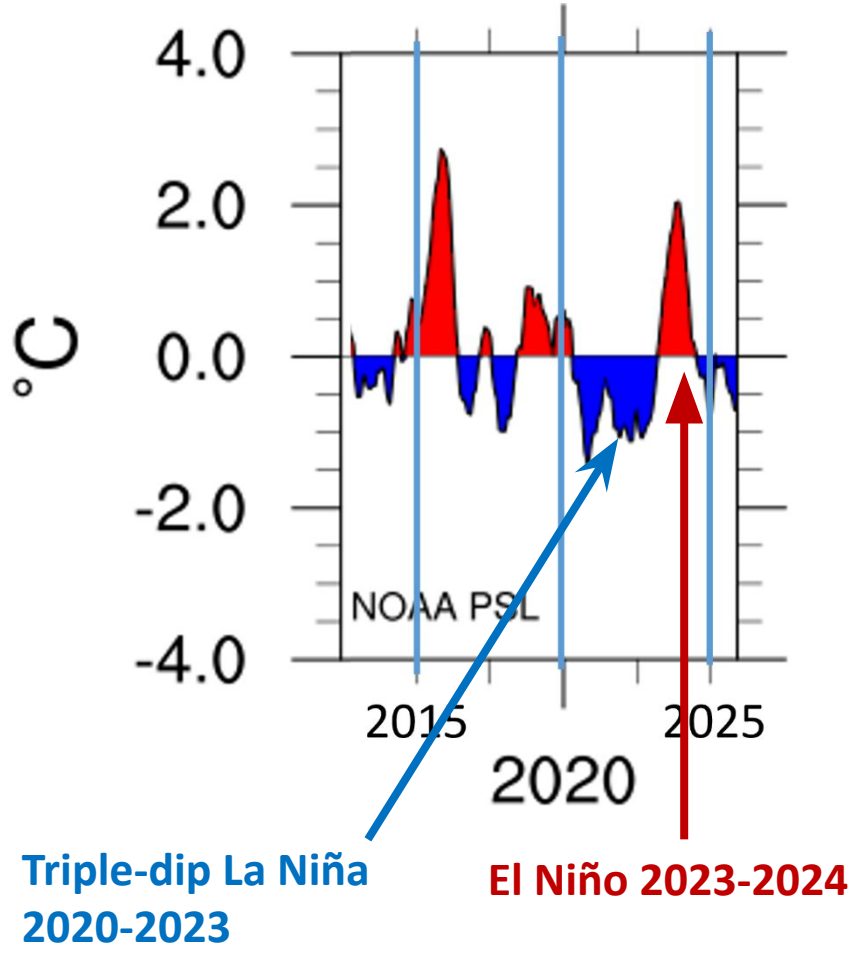
To compare to the actual triple-dip La Niña event, extensions of the hindcast experiments were run out to March 2023 when the observed event transitioned to El Niño

The CESM2 hindcast composite transitioned to El Niño in spring 2022

The E3SMv2 hindcast composite transitioned to El Niño in spring 2023





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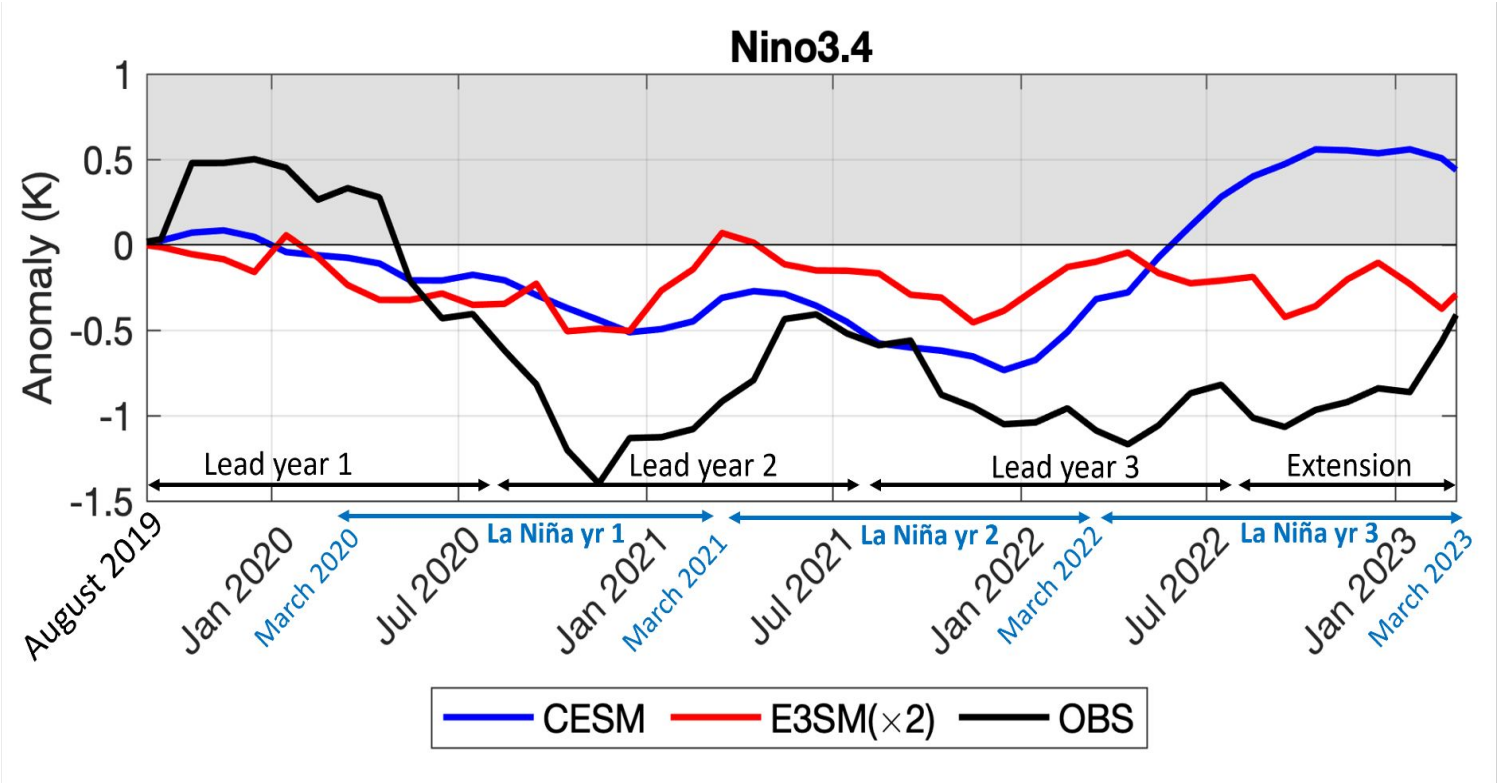
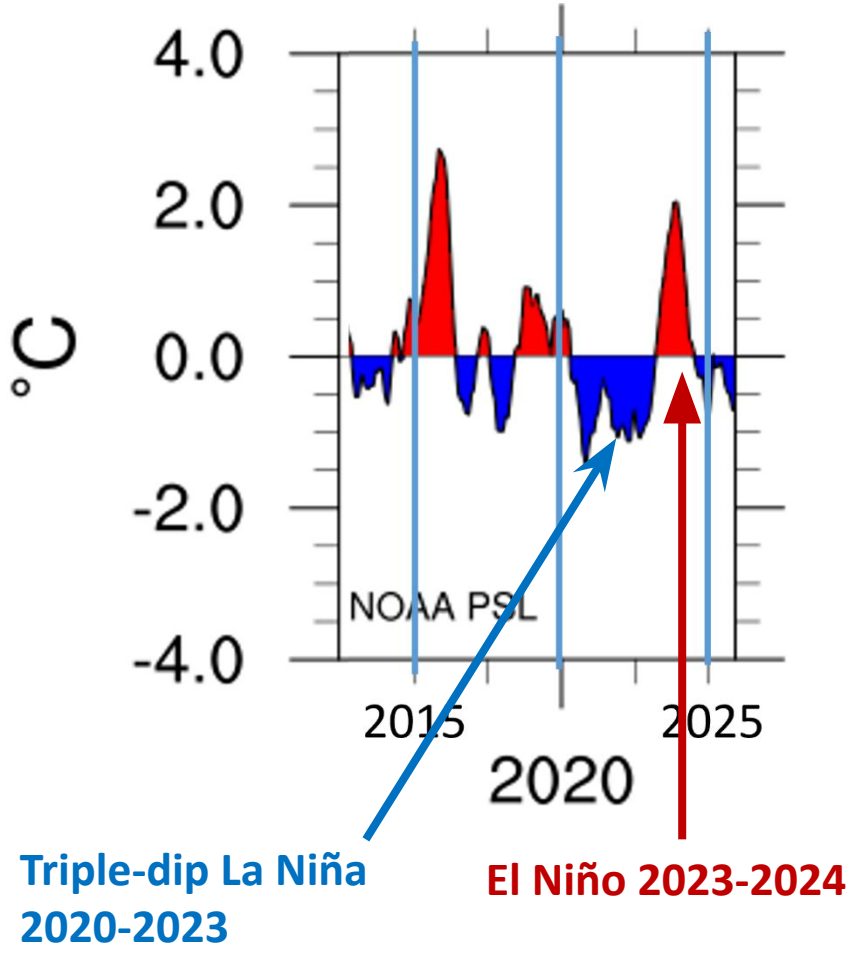
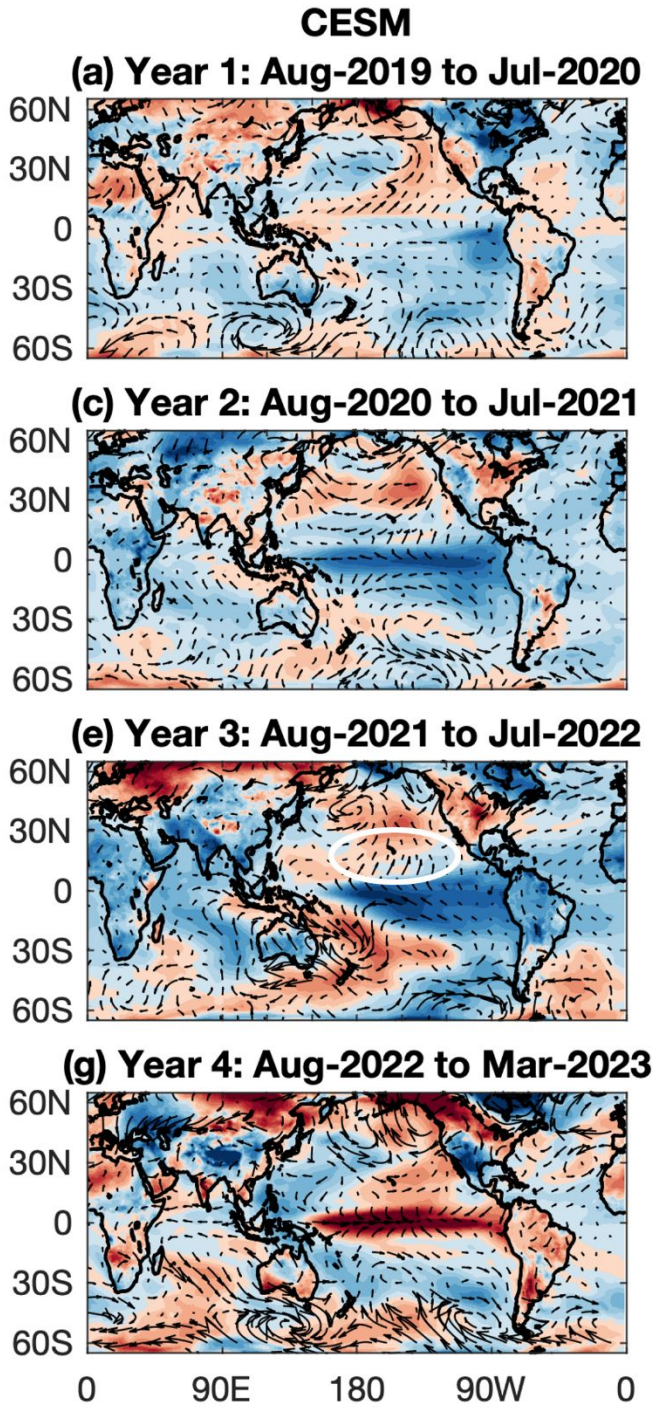
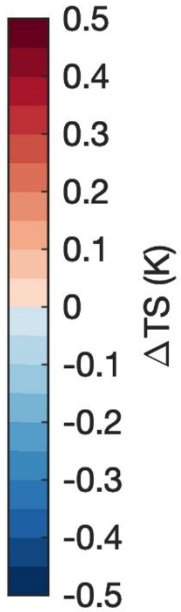
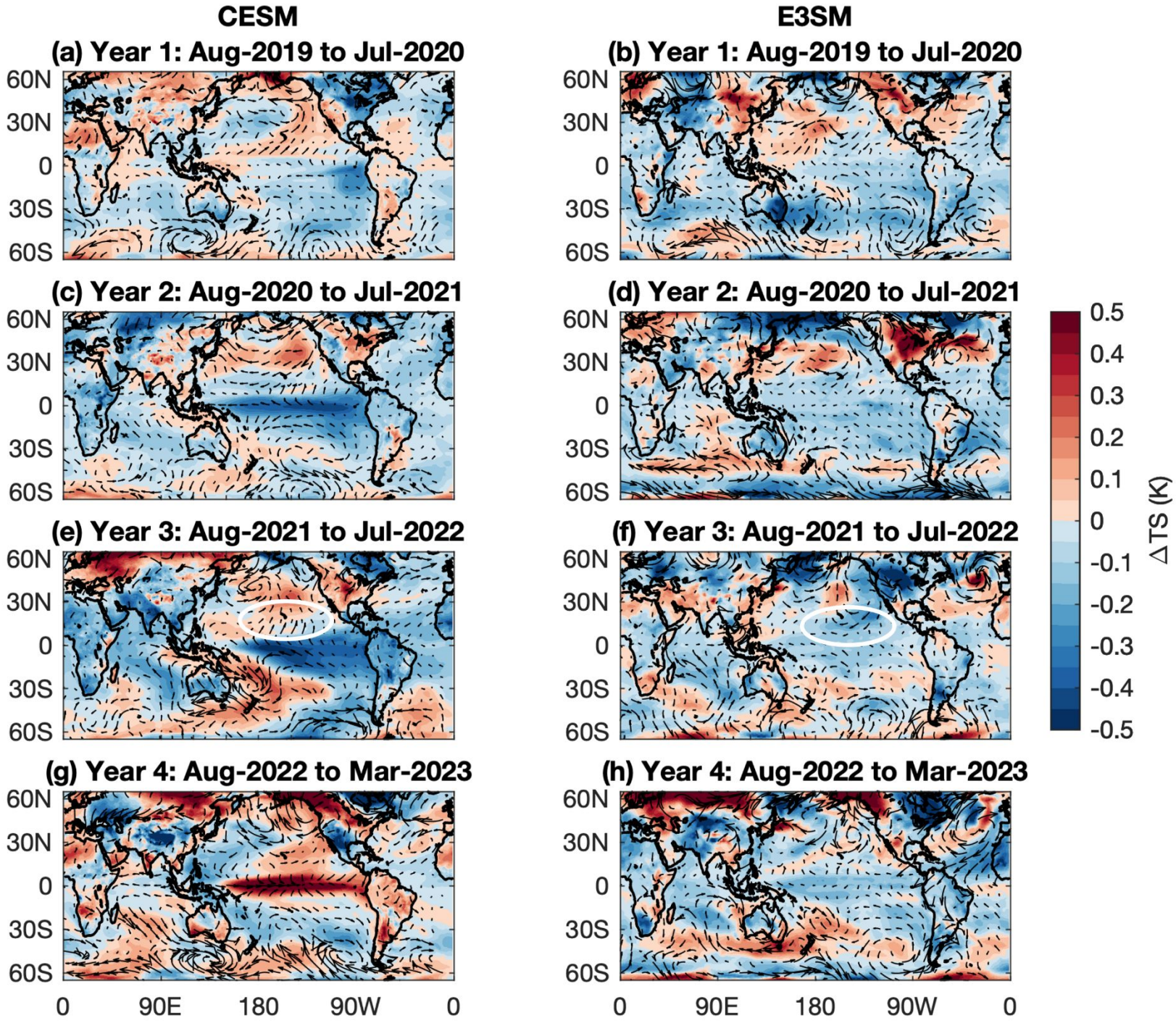








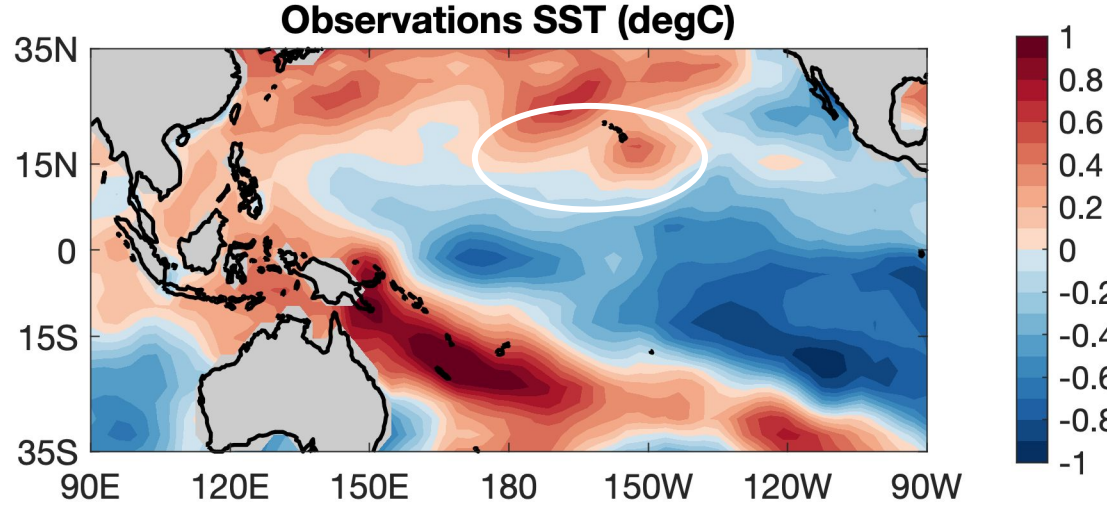
Positive NPMM near Hawaii in CESM forms in lead year 3 (Aug 2021-July 2022) with transition to El Niño in Aug 2022- Mar 2023

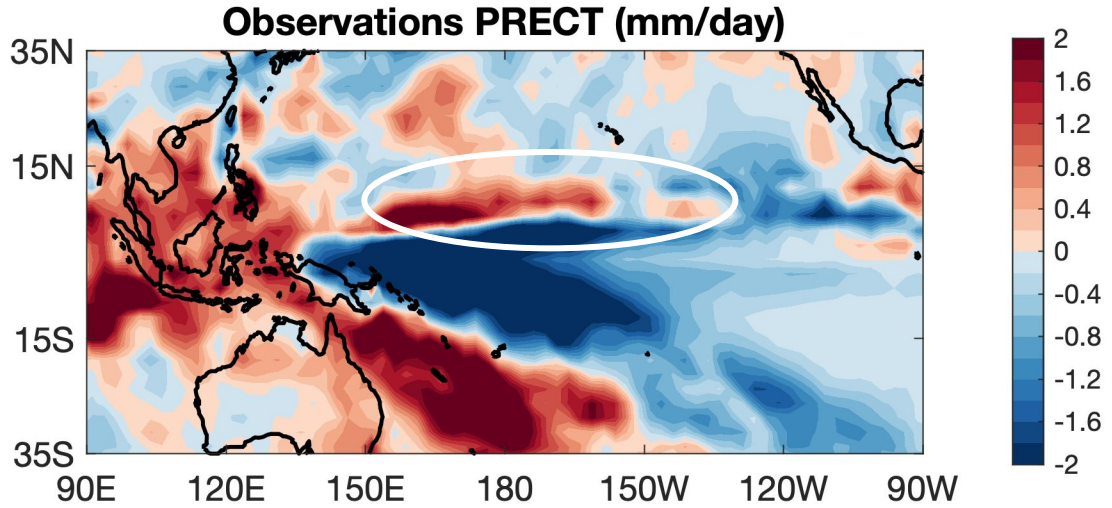


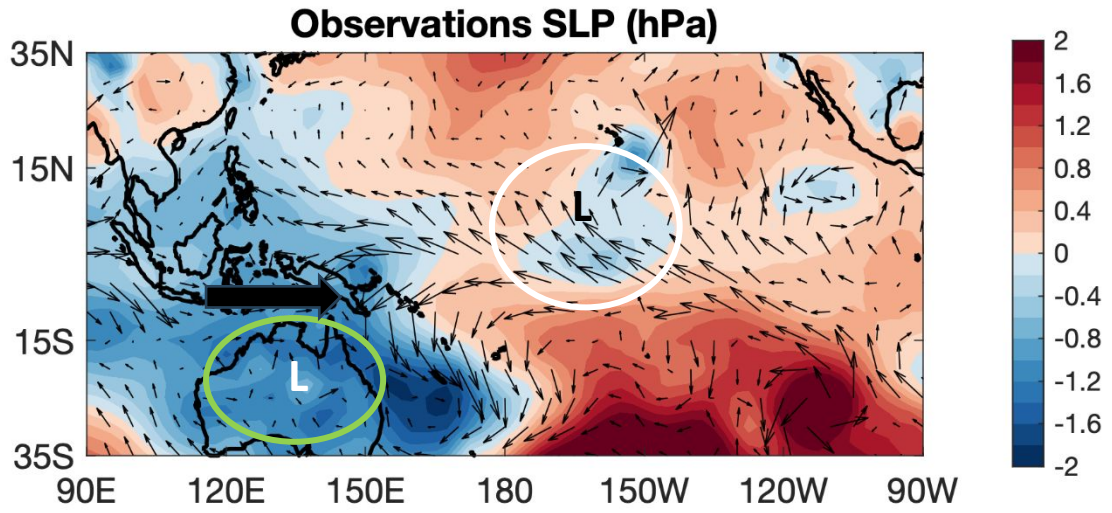
Positive NPMM near Hawaii in CESM forms in lead year 3 (Aug 2021-July 2022) with transition to El Niño in Aug 2022- Mar 2023

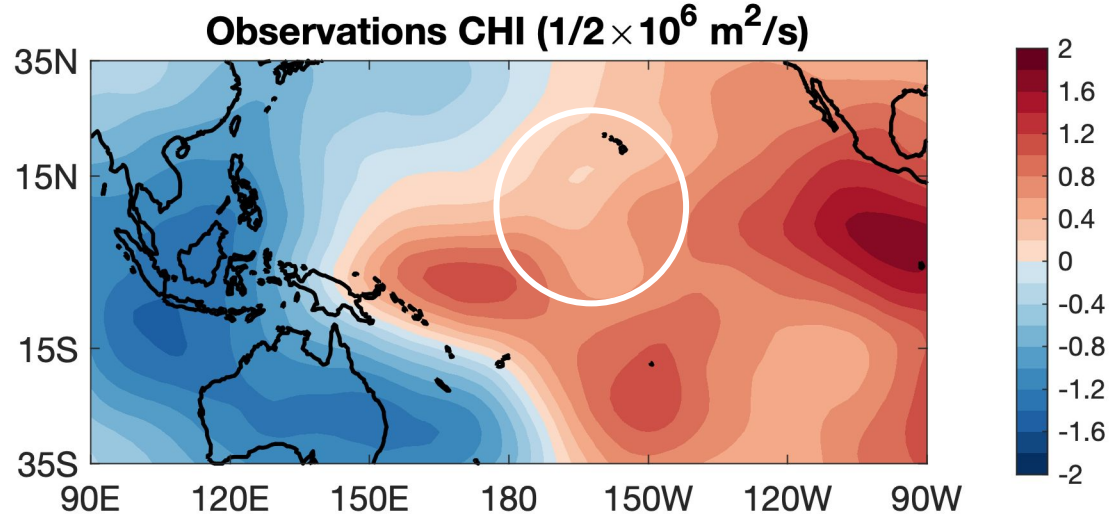
NPMM stays negative near Hawaii in E3SM2 in lead year 3 and La Niña conditions persist into Aug 2022-Mar 2023 as observed

Observed conditions in March 2022-February 2023 leading to end of triple-dip La Niña





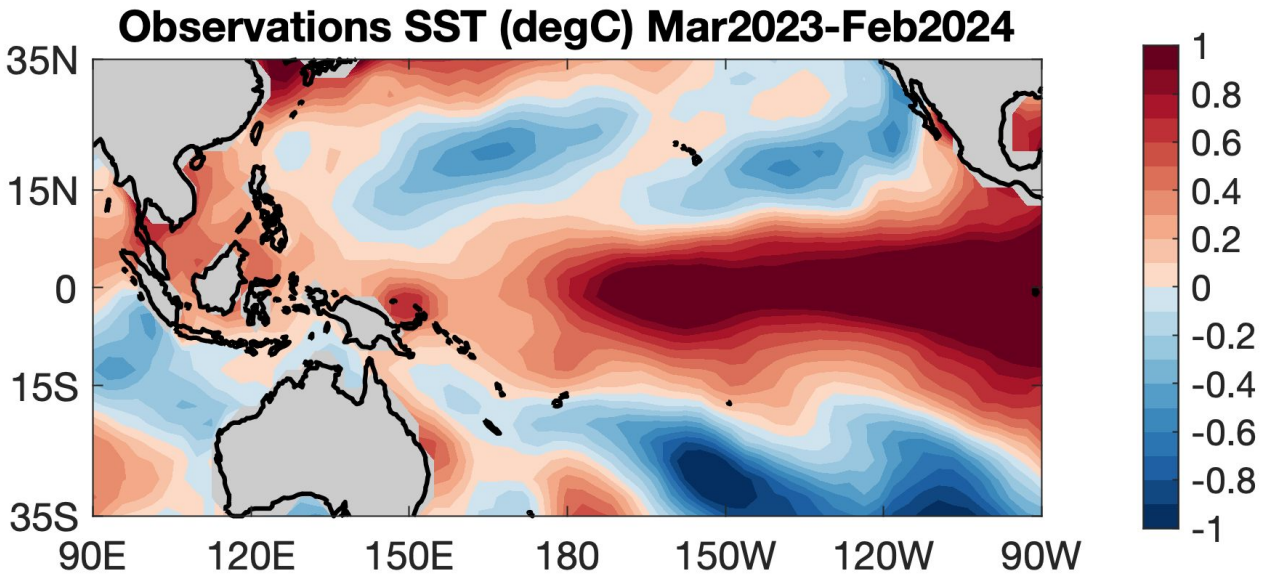


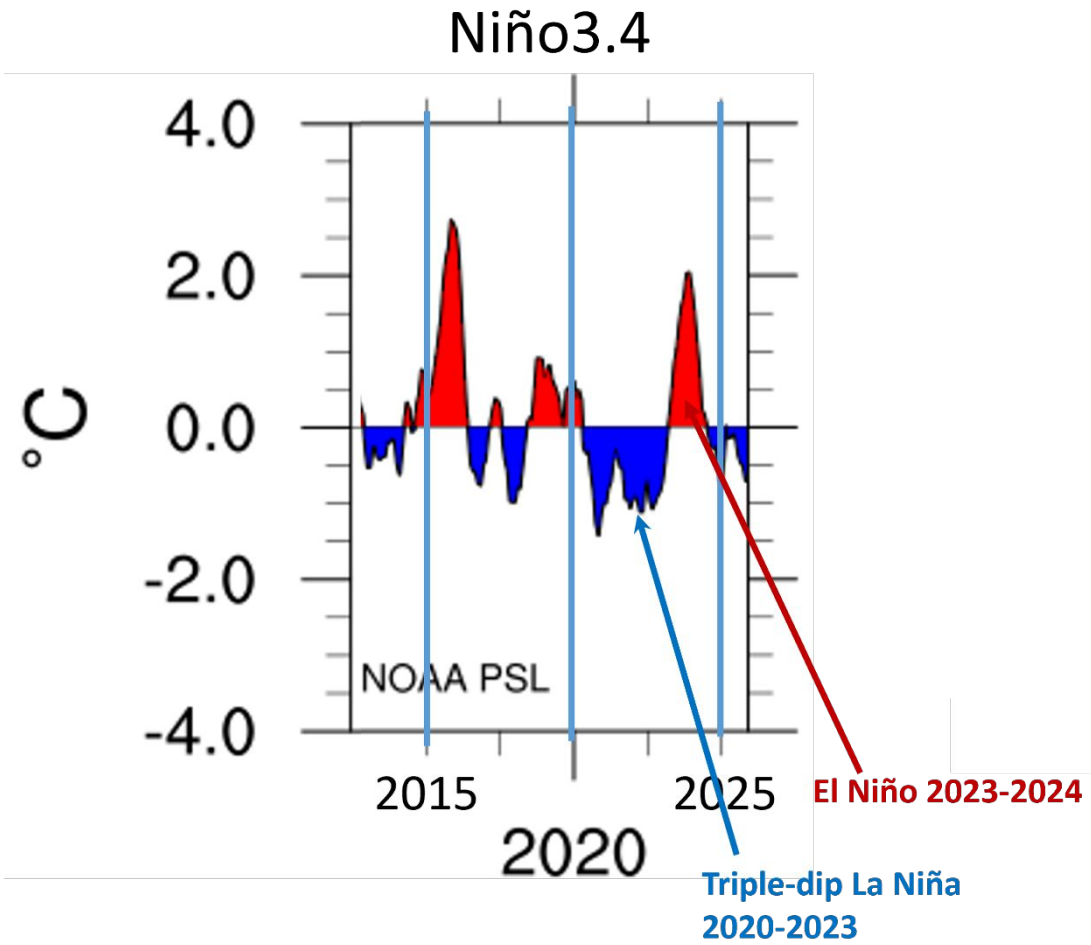


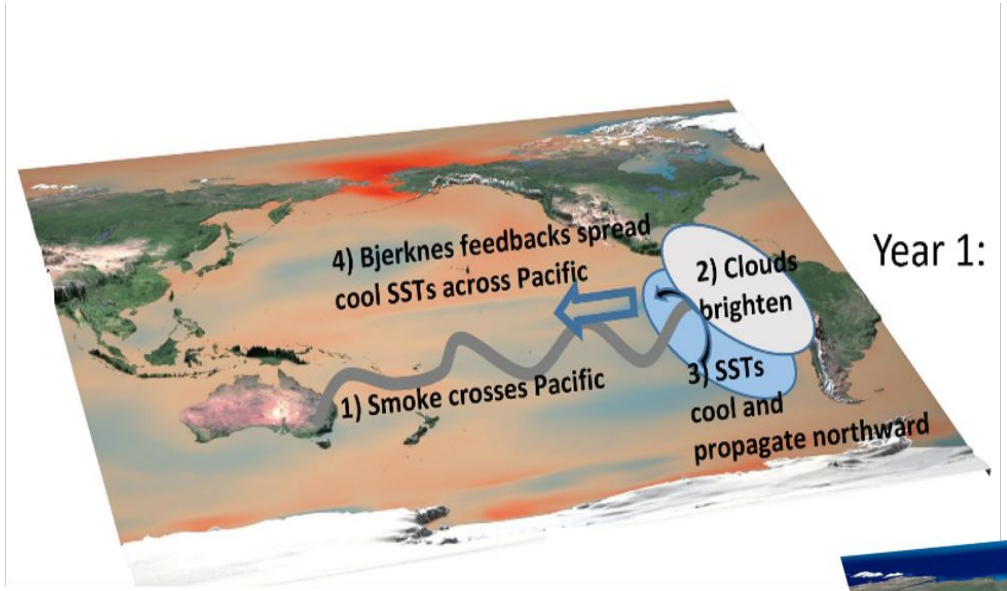
The observed transition to El Niño resembled the model transitions:

- Formation of a positive NPMM SST signal overlaid by negative SLP anomalies
- Enhanced precip near the NPMM, and a weakening of positive 200 hPa velocity potential overhead
- Weakened negative SLP anomalies over the Maritime Continent, and a meridional SLP gradient with westerly wind anomalies

…resulting in the transition to El Niño in 2023-24 and the end of the triple-dip La Niña

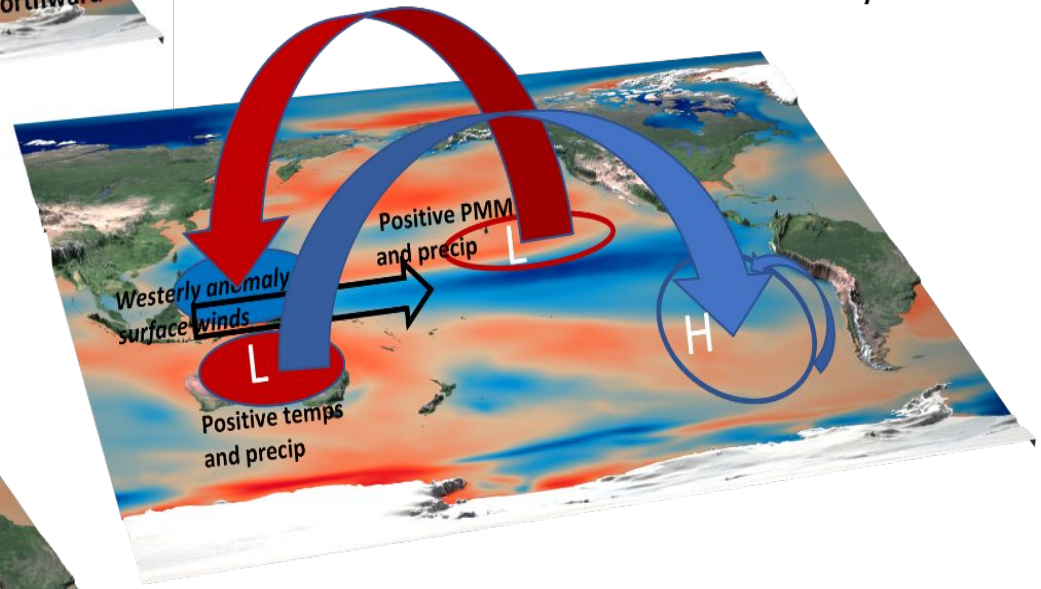




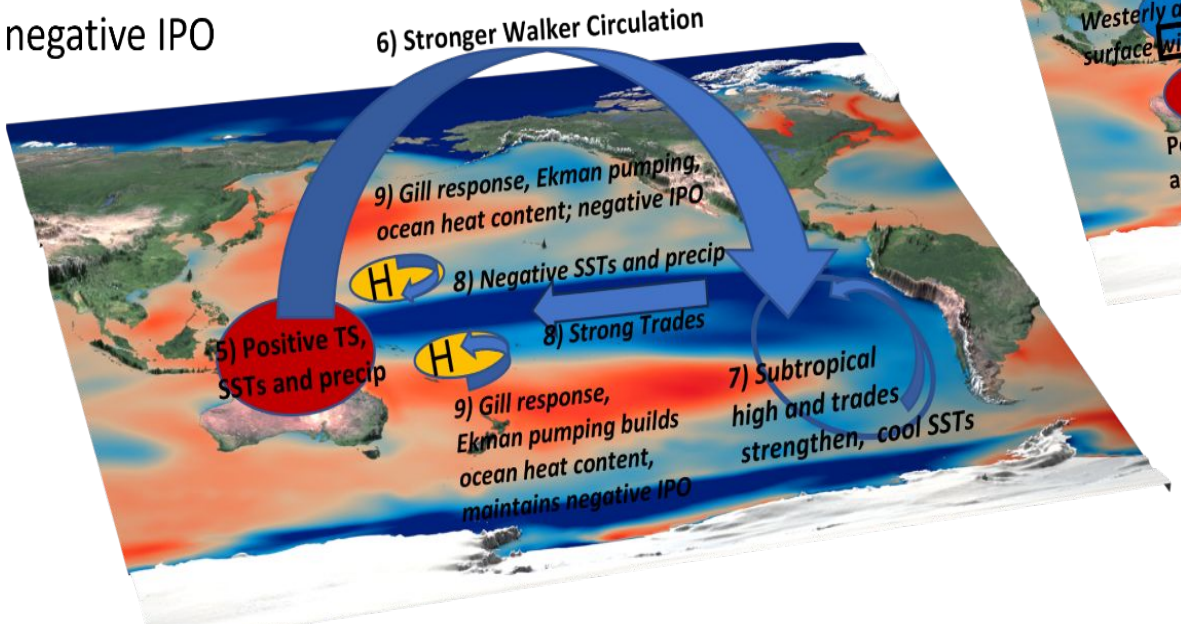


Year 1: Onset

Year 2: Curtailed La Niña in year 2 and transition to El Niño in year 3



Years 2 and 3: Sustained 3-year La Niña and negative IPO



Summary

Smoke from the 2019-2020 Australian wildfires contributed to the initiation of a multi-year La Niña event

The main process that sustains the multi-year event:

Bjerknes feedback through the Walker Circulation that connects strong trade winds across the equatorial Pacific, which act to cool tropical Pacific SSTs; there are warm SSTs and increased precipitation in the western Pacific and a strong subtropical high in the eastern Pacific through the Walker Circulation

Processes that ended the multi-year event:

Positive North Pacific Meridional Mode (see also Liang et al., *Sci.Adv.*, 2025) **that results in an anomalous low in the north-central Pacific with westerly anomaly Trades, as well as an altered Walker Circulation with weakened low pressure north of Australia, an anomalous meridional surface pressure gradient and westerly anomaly surface winds in the western equatorial Pacific to trigger downwelling Kelvin waves and a transition to positive equatorial Pacific SST anomalies**